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(54) Title of the Invention: Excimer Laser Device Using a Laser Light Wavelength Controlling Method and Excimer Exposure Device

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Specifications

1. Title of the Patent: Excimer Laser Device Using a Laser Light Wavelength Controlling Method and Excimer Exposure Device

2. Scope of the Patent's Claims

1. A method to control laser light wavelength, characterized by the fact that a wavelength controlling method is used in order to vary the status of narrow band system elements with a narrow band system using a plurality of narrow band system elements varying the wavelength of the output laser light;

so as to achieve approximately the maximum efficiency of the wavelength selection of each of said narrow band system element per a desired wavelength by setting the status of each of said narrow band system elements.

2. The laser light wavelength control method described in claim 1, characterized by the fact that the setting of each of said narrow band system elements serves to approximately maximize the efficiency of each of said narrow band system elements per the same wavelength;

wherein the status of each of said wavelength selection elements is linked to the initiated changes.

3. An excimer laser device, characterized by the fact that a wavelength controlling method is used in order to vary the status of narrow band system elements with a narrow band system using a plurality of narrow band system elements varying the wavelength of the output laser light;

equipped at the same time with an excimer laser device provided with a function enabling to change the absolute length of the output light so as to achieve approximately the maximum efficiency of wavelength selection of each of said narrow band system element per a desired wavelength by setting the status of each of said narrow band system elements;

equipped with a wavelength control setting device which sets the status of each of said narrow band system elements.

4. The excimer laser device described in claim 3, wherein the status of each of said narrow band system element is linked to the changes so as to approximately maximize the selection efficiency of each of said narrow band element per the same wavelength.

5. The excimer laser device described in claim 3, characterized by the fact that said plurality of narrow band selection elements comprises an etalon or grating or prism, wherein said selection efficiency is the transmittance of said etalon or prism with said wavelength, or the

reflectance of said grating.
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6. The excimer laser device described in claim 3 or claim 4, characterized by the fact that the status of said narrow band system element comprises the angle formed between the optical axis of the prism beams and the reflecting surface of the etalon, or grating, or prism; as well as the index of diffraction of the peripheral medium.

7. The excimer laser device described in any of the claims 3 through 6, characterized by the fact that said multiple etalons have a gap Δh_i, a finesse f_i ($i = 1 \sim n$), wherein when the output wavelength λ of the laser is changed by changing the angle θ_i ($i = 1 \sim n$) formed between the optical axis and the normal line of the reflecting surface of each etalon, the condition specified below will be met at any time for a specified wavelength λ:

$$0.8 \leq [1 + (2\pi f_i)^2 \sin^2 \frac{2\pi \Delta h_i \cos \theta_i}{\lambda}]^{-1} \leq 1$$

wherein all the θ_i ($i = 1 \sim n$) are set so as to meet the condition ($i = 1 \sim n$).

8. The excimer laser device described in any of the claims 3 through 7, characterized by the fact that said narrow band system elements having a longer narrow band half width narrow band elements are mounted inside laser resonator, while said narrow band wavelength half width narrow band elements which have a shorter narrow band half width are mounted outside of said laser resonator.

9. The excimer laser device described in any of the claims 5 through 6, characterized by the fact an etalon is deployed outside and inside of a laser resonator so that the etalon inserted in the inner part of said laser resonator has a wider gap than the gap of the etalon deployed outside of said laser resonator.

10. The excimer laser device described in any of the claims 6 through 9, characterized by the fact that the light path of the laser etalon deployed outside of said laser resonator passes through it at least twice.

11. An excimer laser device which uses a narrow band system with a plurality of narrow band elements, having a function enabling to change the absolute wavelength of the output laser light by changing the status of said narrow band system element;

equipped with a wavelength control device which sets the status of each of said narrow band elements.

3. Detailed Explanation of the Invention

(Sphere of Industrial Use)

This invention relates to an exposure device and an excimer laser, as well as a wavelength selection method used by an excimer laser device having a wavelength narrow band system function.

(Prior Art Technology)

It is known that resolution can be increased by using a shorter wavelength for light exposure with the reduction projection exposure method, which is widely used at present for formation of fine patterns in integrated semiconductor circuits. The reduced projection exposure method using for a light source an excimer laser with shorter ultraviolet wavelengths also attracted attention. According to this method, g rays were applied (with a wavelength of 436 nm) according to prior art with a high voltage mercury lamp, or i rays were applied instead (with a wavelength of 365 nm).

However, the types of optical materials that can be used for transmission of ultraviolet rays, such as KrF excimer lasers, etc., are very limited. That is why it is very difficult to achieve a so called color aberration correction with a reduced projection exposure lens while using the reduced projection exposure method and said excimer laser as a light source. Specifically, exposure is commonly performed by using a reduced projection lens without applying color aberration correction when the wavelength of an excimer laser which has a natural spectral width of about 0.5 nm with this method is used together with a narrow band system below 5/100 nm. It is also common to combine with the above mentioned narrow band wavelength system multiple etalons, prisms, and similar narrow band wavelength elements.

In addition, the excimer laser reduced projection exposure method has been also described for instance in the January issue of the publication Solid State Technology, (January 1987), page 71 through 76).

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Problems To Be Solved By This Invention

When the above mentioned prior art method was used and the status of said narrow band wavelength system element (for instance the size of the gap in an etalon or the angle of the optical axis to the reflecting surface of an etalon, etc.) fluctuated due for example to factors such as oscillations or heat, etc., the problem was that this would be accompanied also by fluctuations of the central wavelength (called hereinafter output wavelength) during the distribution of the wavelength spectrum. Because when similar wavelength fluctuations occurred, the image formation surface of the reduced projection lens was eventually moved in the direction

of the optical axis, the mask pattern could no longer be copied under optimal conditions. That is why the absolute value of said output wavelength created in the narrow band system had to be monitored, feedback containing these fluctuations had to be applied to the status of said narrow wavelength band system element (for example through a fine adjustment of the angle formed between the optical axis and the reflecting surface of the etalon), because said output wavelength had to be maintained constant at all times. A similar fine adjusting function for adjustment of the wavelength is effective not only with status fluctuations of said narrow band system element, but also when used to correct fluctuations of the image forming position caused by air pressure fluctuations or status fluctuations of a reduced projection lens, etc.

However, the status of a narrow band system element generally also has a very strong influence on the status of the distribution of the wavelength spectrum as well as on the output power.

In particular when a plurality of narrow band system elements is used, the output power will be dramatically reduced even if there are independent fluctuations of only one of these narrow band system elements. Moreover, a sideband wave will be often also generated at this time with an absolute wavelength above the specified wavelength. A similar sideband wave reduces the contrast of the optical image projected during the pattern exposure, causing a deteriorating pattern formation.

The purpose of this invention is to provide an excimer laser device which has the above described function, and which provides a wavelength varying method enabling to vary the absolute wavelength without generating a sideband wave, while suppressing to the minimum reduction of the output power. This also makes it possible to obtain an exposure device enabling to conduct exposure in a very simple manner while an optimal status of an excimer laser device is maintained by using said narrow band system method.

(Means To Solve Problems)

The above mentioned purpose of this invention is achieved with sequential variations aimed at maximizing the efficiency of the wavelength selection per the same wavelength applied to the status of each element in a plurality of narrow band elements related to wavelengths using a narrow band system.

In this case, the status of the narrow band system element, comprising an etalon gap, etalon, grating, prism and other reflecting surfaces of a narrow band system element of a laser device, will form an optical angle with the optical axis of the device, and with the refractive index, etc., of said narrow band system element or of the peripheral medium. The index of refraction of the peripheral medium can be changed for instance by increasing or reducing the air pressure in the periphery of the element.

In addition, wavelength selection efficiency η can be calculated for instance as follows:

$$\eta = \int_{\lambda_0 - \Delta\lambda/2}^{\lambda_0 + \Delta\lambda/2} \frac{I(\lambda)}{I(\lambda)} d\lambda$$

Expressing the following quantities:

λ: wavelength,
λ_0: desired central wave,
$\Delta\lambda$: half-value width narrow band system wavelength created with each narrow band system element,
$I_0(\lambda)$: natural wavelength spectrum
$I(\lambda)$: the wavelength spectrum created by a narrow band system with each narrow band system element.

(Operation)

Next, the operation of this example will be explained in a case using 2 etalons to simplify the explanation. As shown in Figure 4, 2 etalons having respective gaps Δh_1, Δh_2 ($\Delta h_1 > \Delta h_2$) are used with the normal method of reflecting surfaces in each etalons to form optical axis angles θ_1, θ_2. The relationship between the transmittance T of each of said etalons, wavelength λ, angle θ_1 or θ_2 can be expressed by the following formulas:

$$T_1(\theta_1, \lambda) = [1 + (2\pi f)^2 \sin^2 \frac{2\pi \Delta h_1 \cos\theta_1}{\lambda}]^{-1} \quad (1)$$

$$T_2(\theta_2, \lambda) = [1 + (2\pi f)^2 \sin^2 \frac{2\pi \Delta h_2 \cos\theta_2}{\lambda}]^{-1} \quad (2)$$

In this case, λ is the wavelength of the exposure light and f is the finesse of the etalon. The total transmittance T with two etalons thus equals $T = T_1 \times T_2$. If the natural wavelength spectrum of the excimer laser is $I_0(\lambda)$, the wavelength spectrum $I(\lambda)$ of the output light passing through the etalon will equal:

$$I(\lambda) = T_1(\theta_1, \lambda) \times T_1(\theta_2, \lambda) \times I_0(\lambda) \quad (3)$$

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Figure 5 explains the situation occurring with respect to changes of $I(\lambda)$ when θ_2 is fixed

and θ_1 is changed. In addition, Figures 6 is the same diagram explaining the situation in a case when θ_1 is fixed and θ_2 is changed. In either of these cases it is possible to change the wavelength output by shifting the angle of the etalon.

However, if at the same time the output strength also fluctuates due to the setting of the angle of said etalons, it was determined that instead of 1 peak of the output wavelength spectrum, a peak will be eventually reached in 2 or 3 locations. Neither of the above explained facts is a desirable situation. Figure 7 indicates the function of said output strengths θ_1 and θ_2 only from the viewpoint of the output strength.

As one can see from this figure, when either θ_1 or θ_2 is fixed and the other output strength item fluctuates, it is clear the output strength will be characterized by violent fluctuations. Although the above description used a case with 2 etalons, completely identical characteristics will be obtained also in a case when a narrow band wavelength system element is used in addition to the etalons. On the other hand, as shown in Figure 6, when fluctuations of θ_1 and θ_2 are induced along the ridge shaped part, this makes it possible to suppress the fluctuations and the fluctuations of the output strength will thus be very small.

In addition, the output wavelength spectrum at this point will have a single peak shape and the peak waveform will not fluctuate. These conditions can be described as follows:

$$T_1(\theta_1, \lambda) = T_1 \max$$
$$T_2(\theta_2, \lambda) = T_2 \max \qquad (4)$$

(Embodiments)

The following is an explanation of an embodiment of this invention based on the enclosed figures. Figure 1 shows a construction diagram of one embodiment of an excimer laser device according to this invention, Figure 2 is a graph explaining the wavelength adjusting method, Figure 3 is a construction diagram explaining another embodiment of the excimer laser of this invention, and Figure 7 is a graph showing the characteristics of the excimer laser output according to the principle of this invention.

Embodiment 1

Figure 1 is a construction diagram explaining Embodiment 1 of this invention. In this device which contains reflecting mirror 1, KrF excimer laser gas chamber 2, etalon 3, output mirror 4, etalon 5, etalon angle adjusting devices 6 and 7, output wavelength controlling device 8, output wavelength monitoring device 9, and output strength monitoring device 10, each element of the above described construction is deployed as shown in Figure 1.

In addition, 11 is a monitor beam splitter and 12 is a reflecting mirror for a monitor. Because said etalons 3 and 5 have a gap of 0.5 mm and 0.05 mm and etalon 3 distributes the

spectrum of the laser light oscillated between reflecting mirror 1 and output mirror 4 within the range of the natural spectrum band (248.1 ~ 248.7 nm) of KrF excimer laser, there will be several peak-shaped spectrums in the narrow band system of the half-value width of about 3/100 nm distributed with about the same wavelength interval. Etalon 5 allows only 1 spectral peak output from output mirror 4 to pass through a plurality of narrow band systems. Etalon angle adjusting devices 6 and 7 adjust the angle at which reflecting surfaces of respective etalons 3 and 5 are set to the optical axis. Wavelength monitoring device 9 detects the absolute value of the peak wavelength output from wavelength monitoring device 9. In addition, output strength monitoring device 10 detects the strength of the output light. The results obtained from said monitoring device can be provided, when this is necessary, as feedback to output wavelength controlling device 8, and the output device wavelength controlling device 8 transmits to the etalon angle adjusting devices 6 and 7 the signal required to achieve a desired output strength or wavelength.

Etalon angle adjusting devices 6 and 7 adjust the angle formed between the reflecting surfaces of etalons 3 and 5 and the optical axis based on said signals. In this case, said output wavelength controlling device 8 is provided with a function enabling to send the signal to etalon angle adjusting device 6 and 7 so as to create sufficient fluctuations as explained in Formula (4) for 2 angles as explained above in accordance with the operation.

In addition, it is possible to use also another composition of the gas of the excimer laser, since this composition is not necessarily limited to the example mentioned in the embodiment. Moreover, neither is the gap of the etalon limited to the value mentioned in this embodiment. However, as shown in Figure 1, it is desirable when the gap of etalon 3 which is deployed inside a resonator is greater than the gap of etalon 5 which is deployed outside of said resonator.

A similar design thus makes it possible to increase the strength of the output laser light. This can be attributed to the fact that an efficient activation of the gas or of the excitation status inside the resonator is enabled thanks to the resonance of multiple wavelengths which can be selected within the natural spectrum of excimer laser light as long as the etalon has a sufficiently wide gap.

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In addition, because the laser light passes inside the resonator back and forth several times, this makes it possible to increase the efficiency ratio per an etalon mounted in the resonator, enabling to increase the effective finesse. Since the half-value width of the spectrum of the narrow band system is support by an etalon with a wide gap, is it possible to further reduce said half-value width by deploying an etalon having a wide gap inside a resonator. On the other hand, in order to achieve a real and effective increase of the finesse of an etalon mounted outside of the laser resonator, it is effective to use for instance a setting in which the optical path of the laser light passes at least twice through said etalon.

An example of the method used to set the optimal conditions with the device indicated in

the embodiment will be explained next. First, the angle of only one of the etalons 3 or 5 is adjusted independently to achieve the maximum output strength by using output strength monitoring device 10 and wavelength controlling device 8. Figure 2 explains the adjusting method. Broken line 13 indicates the natural spectrum of an excimer laser, 14 shows the transmittance of etalon 5, and 15 indicates the peak of the narrow band system. As shown in Figure 2 (b), this method will match the wavelength applied with the maximum transmittance to etalon 5 with one wavelength in a plurality of peaks of the spectrum passing through etalon 3. In other words, the relationship shown in Formula (4) above is satisfied. Next, the angle of etalons 3 and 5 will be adjusted as shown in Figure 2 (c) while the relationship of said Formula (4) is satisfied until the value desired for the output wavelength has been reached.

The wavelength control can performed at this point mainly according to two methods.

According to the first method, the strength of the output light is varied by varying the angle of etalon 3, via output strength monitoring device 10, wavelength controlling device 6, and etalon angle adjusting device 7, and a constant feedback is provided for the angle of etalon 5, enabling to vary the angle of etalon 3 until a desired wavelength is reached while the maximum output is maintained.

According to the second method, the rotational amount of the angle of etalons 3 and 5 is calculated in advance with a wavelength controlling device based on the difference between the desired wavelength and the present wavelength measured by wavelength monitoring device 9 and an angle rotating signal is sent to etalon angle adjusting device 6 and 7. Optimal results will be obtained regardless of which method is used.

When the output wavelength used in the present device is changed within the range of 248.nm ~ 248.6 nm, deterioration of the output strength can be greatly reduced by matching approximately the wavelength dependency of the strength generated in the natural spectrum of the excimer laser. It is also possible to scan the absolute wavelength while the spectral shape is maintained with a single peak of the half-valued width at approximately 3/1,000 nm, regardless of generation of sideband wave during this time period.

Embodiment 2

Embodiment 2 of this invention will be explained on the reference provided in Figure 3.

The excimer laser device shown in Figure 3 uses instead of etalon 3 of the excimer laser device shown in Embodiment 1 grating 16 which is mounted between reflecting mirror 1 and excimer laser gas chamber 2. In addition, a grating angle adjusting device 17 is deployed instead of the etalon angle adjusting device 6. The setting position and the angle of reflecting mirror 1 is thus changed according to the diffraction angle of the laser light with said grating 16. The same effect as the one achieved in Embodiment 1 will be obtained also in this embodiment.

It is also possible to use a different deployment of the narrow band system elements, without limiting the design of the present embodiment to the example explained in Embodiment 1.

Embodiment 3

The embodiment utilizes a variable wavelength function of the excimer laser device shown in Embodiment 1 to realize a so called multiple image formation exposure method (commonly called the FLEX method). Specifically, multiple exposure is conducted by setting the image formation surface in different positions in the direction of the optical axis by using the color aberration characteristics of a projecting lens and the same mask exposure is conducted while different wavelengths are used.

The exposure was conducted per each wavelength which was set first to the wavelength of 248.39 nm and then to 248.41, while the maximum output, varied so as to achieve coincidence with the ridge shape as shown in Figure 6, was applied to angles θ_1 and θ_2 formed between the optical axis and the normal line of the reflecting surface of etalons 3 and 5 shown in Figure 1. The distance between the image formation position used with said second exposure was about 2.5 μm. In addition, the fluctuation of the output strength accompanying the above described changes was less than 5%.

The present embodiment made it possible to achieve a 0.3 μm contact hole pattern having a focusing depth resolution of at least ± 1.5 μm.

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Also, the focusing depth of the present embodiment was at least twice the focusing strength of a case in which the present embodiment was not utilized.

(Effect of the Invention)

As was explained above, this invention makes it possible to obtain an excimer laser device and an exposure device characterized by the fact that when the wavelength controlling method of this invention is used, the wavelength of the output laser light can be varied with a narrow band system using a plurality of narrow band wavelength system elements. According to the laser light wavelength controlling method changing the absolute wavelength of the output laser light, the status of respective elements of the narrow band system is set so as to obtain approximately the maximum efficiency of the wavelength selection of each of said elements in the narrow band system per a desired wavelength. This makes it possible to suppress to the minimum reduced output strength accompanying the changes of said output wavelength and because the spectral status of the wavelength of said narrow band system is maintained, it is thus possible to obtain an excimer laser device and an exposure device having all of the above

mentioned characteristics.

4. Brief Description of Figures

Figure 1 is a construction diagram showing one embodiment of an excimer laser device of this invention, Figure 2 is a diagram explaining the wavelength adjustment method used with said embodiment, Figure 3 is a construction diagram explaining another embodiment of an excimer laser device of this invention, Figure 4 is a diagram explaining the principle of the operation of this invention, Figure 5 and Figure 6 are diagrams showing the output characteristics of an excimer laser according to prior art, and Figure 7 is a diagram showing the output characteristics of an excimer laser displayed according to the principle of this invention.

2	...	excimer laser gas chamber
3, 5	...	etalons (narrow band system elements)
8	...	wavelength controlling device
16	...	grating (narrow band system element).

Representative: Junnosuke Nakamura, patent attorney.

(Figure 1, 2, 3, and 4)

(Figure 2)

2: excimer laser gas chamber
3, 5: etalons (narrow band system elements)
8: wavelength controlling device
11: grating